Two-Step Locating System for Harsh Marine Port Environments

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***Abstract*—with the increasing amount of traffic volume on containers, not only identification but also location estimation of assets has become an important issue in logistics automation in a port environment. The locating system is generally composed of tags, readers, and a location engine. Tags are attached to the object and obtain information via communication with readers that are installed around the tags. The engine continuously attempts to estimate the location of tags by using the obtained information. However, if we attempt to apply this common locating system to a port environment for logistics automation, the system performance is degraded because there are many steel obstacles that cause interference in the RF communication and measurement. In this paper, we propose a two-step approach for location estimation in harsh port environments. We divided readers into two types (fixed and mobile readers); hence, the location method operates in two steps for efficient wireless communication and precise measurement. We implemented all the system components and installed these at a real port for evaluation. The communication and estimation success rate is more than 50% better than that of the existing general locating system, and the location precision is substantially increased.**

***Index Terms*—port environment; two-step locating system; port RTLS; location estimation; localization**

I. Introduction

Considering the increasing amount of cargo transportation and traffic volume on containers, labor and maintenance costs can be reduced by logistics automation, which can be realized by efficient processing. In particular, automation of the real-time management of assets in a port logistics environment is an important issue. Accordingly, many technologies have been researched in a wide area, and many standards related to RFID, security, localization, etc., have been developed [1][2][3][4][5][6].

The locating system can be used for tracking the location of assets in real time. These systems are generally composed of three components—tags, readers (or location sensors), and a location engine. Readers receive beacons from tags and estimate time or distances between the tags and themselves. Further, they forward these estimated distances to the location engine, and the engine then estimates the coordinates of each tag.

The components of the system generally communicate with each other through an RF communication medium in a wide area such as that of a port environment. However, the non-line-of-sight (NLOS) error can be a critical problem of these location systems. If there is an obstacle—generally made of steel—between two nodes, signals may not directly reach the destination because of reflection or scattering. In this case, it is difficult to collect the measurement information, and the ranging value, if collected, will be considerably longer than the actual distance. Unfortunately, there are many obstacles made of steel, such as containers or heavy equipment, in the port environment. If we attempt to apply a general locating system to the port, these factors lead to critical errors and dramatically reduce the system performance. Therefore, it is essential to eliminate these errors.

In this paper, we suggest a new approach to location estimation in port environments. We first introduce the properties of the environment and suggest a two-step locating system for efficient measurement using RF communication. Further, we propose the installation of each component and apply this system to a real port for evaluation. This paper is organized as follows: The next section discusses the properties of a port environment and wireless communication. In section 3, we describe our new location estimation method. The installation of the proposed system in a real port and its evaluation are presented in section 4, and the conclusion is provided in section 5.

II. Related Works

A. Real-Time Locating System (RTLS)

In general, RTLSs are divided into two categories: one-way and two-way locating systems [9].

In a one-way locating system, the tags only radiate the signal frequently. Received signal strength (RSS) is one of the one-way systems; this method simply uses the attenuation of RSS between a receiver and a sender for estimating the location. The method is easy to implement, but its accuracy is low [10]. The time difference of arrival (TDOA) uses the time difference between two nodes for estimating the location [11]. Further, the time of flight (TOF) uses the flight time between the receiver and the sender. These methods are relatively precise, but both of these need time synchronization. This leads to a processing and implementation overhead to the system.

In a two-way locating system, each tag and reader exchange the message to measure the round trip time (RTT). One half of RTT indicates the flight time of a signal and the distance

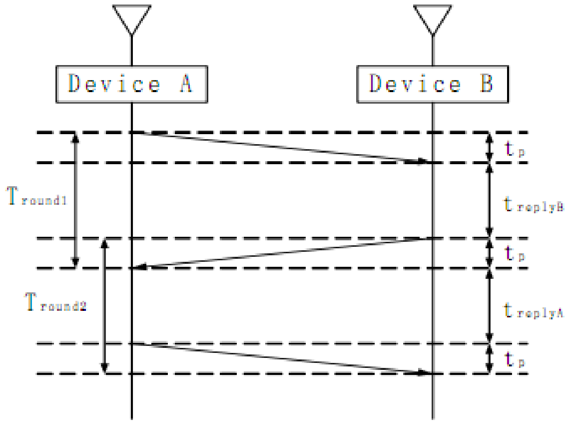

Fig. 1. SDS-TWR : Symmetric Double-Sided Two-Way Ranging

between the tag and the reader. After measuring the distance, a location can be calculated by using trilateration. This system is relatively precise and does not need any time synchronization devices or modules. Nanotron suggests a transceiver IC and symmetrical double-sided two-way ranging (SDS-TWR) for ranging measurement [7]. This technology can be applied to an outdoor area such as a port environment [3][4][13].

B. Properties of port environments

The field in a port has containers that are piled in the form of a grid. A transfer crane (TC) stacks containers that are moved by a yard tractor(YT) on the ground. A TC runs along a railway on a straight line, and an YT has to move on its own pre-defined path. The height of the container should be 2.62 m according to the ISO standards, and the containers can be piled up to five stories high (16 m). Further, the pathway between the container stacks is 25-30 m wide. A TC, shown in Fig. 2, is 30 m high and is used for stacking and moving containers. Moreover, light towers more than 30 m tall are installed in a container yard for night work.

For applying the locating system to a port, a reader must be installed at a high position for line-of-sight (LOS)-conditioned communication between itself and a tag, which leads to precise measurement. Therefore, readers are generally installed at the top of light towers with directional antennas[3]. However, when an YT runs a pathway between the stacks of containers, LOS-conditioned communication cannot be guaranteed because the pathways of an YT between the container stacks are too narrow to communicate with other devices.

III. Two-step locating system for port environments

A. Basic protocol: A two-way locating system

A locating system is generally composed of tags, readers and a location engine. The operation involves three phases: blink, measurement, and estimation, as shown in Fig. 4. At first, a tag radiates a short message (beacon) after certain randomized time. Some of the readers receive the beacon

Fig. 2. Container yard in a port environment (top: YT, bottom: TC)

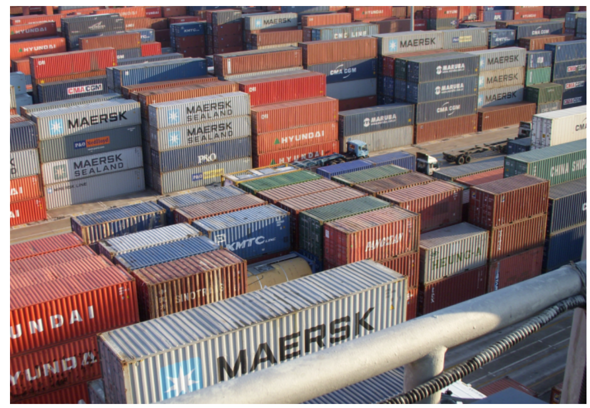

Fig. 3. View from the top of a light tower: cannot directly communicate with YTs well

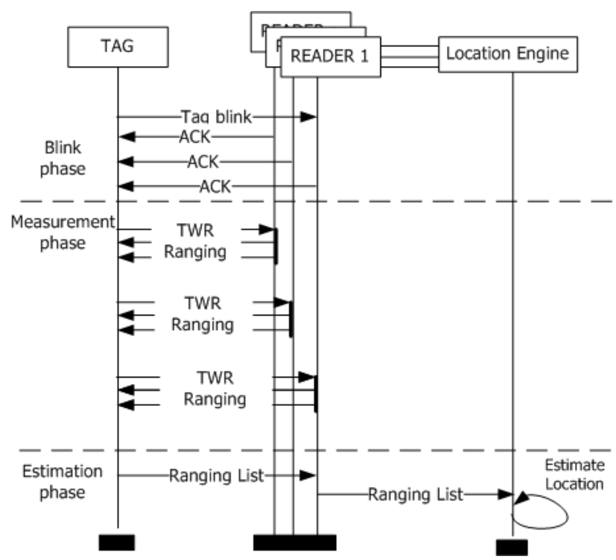

Fig. 4. Protocol of a basic two-way locating system

and reply to the tag (ACK). After receiving ACK, the tag makes a list of readers and starts measuring distances (ranging) between itself and the readers in the list. Then, the tag sends a ranging list to the location engine.

The location engine estimates the location of the tag using a lateration method with distance information in the estimation phase. If the number of collected distance information is more than three, the engine attempts to use multi-lateration, which

$$ex = \frac{(y_b - y_a)C_3 - (y_c - y_b)C_1}{[(x_c - x_b)(y_b - y_a) - (x_b - x_a)(y_c - y_b)]}$$

$$ey = \frac{(x_b - x_a)C_3 - (x_c - x_b)C_1}{[(y_c - y_b)(x_b - x_a) - (y_b - y_a)(x_c - x_b)]}$$

where

$$C_1 = \frac{1}{2}(||x_b||^2 - ||x_a||^2 + cr_a^2 - cr_b^2)$$

$$C_2 = \frac{1}{2}(||x_c||^2 - ||x_b||^2 + cr_b^2 - cr_c^2)$$

Fig. 5. Multi-lateration using least squares

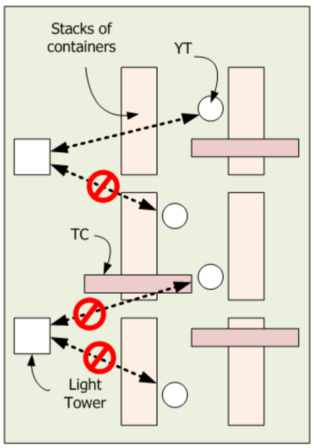

Fig. 6. NLOS problem on a port environment(top view) : the range error can be occurred when a tag cannot communicate with readers in LOS condition. The location cannot be estimated or includes lots of errors.

can minimize the error using the least square estimation, as shown in Fig. 5 [9][10]. cr_a, cr_b, and cr_c denote the distance from each reader a, b, and c. (x_a, y_a) is the location of each reader and the estimated location of the tag is (ex_k, ey_k).

B. Installation of system components

As mentioned earlier, the direct application of the locating system discussed in section 2-A to a port environment cannot guarantee a good performance of the system because of the NLOS environments between a reader and a tag. In this section, we attempt to divide the general system into two steps for minimizing the shadowed area of wireless communication and enhancing the system performance.

First, the readers are divided into two categories: a fixed reader and a mobile reader. The fixed reader is installed at a high position on a light tower; this position is as high as the TC as mentioned above. Because the fixed reader is stationary, it can be a reference node of the system. The mobile reader is attached at a TC and has three or more antennas with an equal number of RF modules. One is an omnidirectional antenna at the top of the TC for communication with fixed readers, and the others are directional antennas for direct communication with tags. Further, a tag with a small antenna is installed at the top of each YT, approximately 2 to 3 m from the ground.

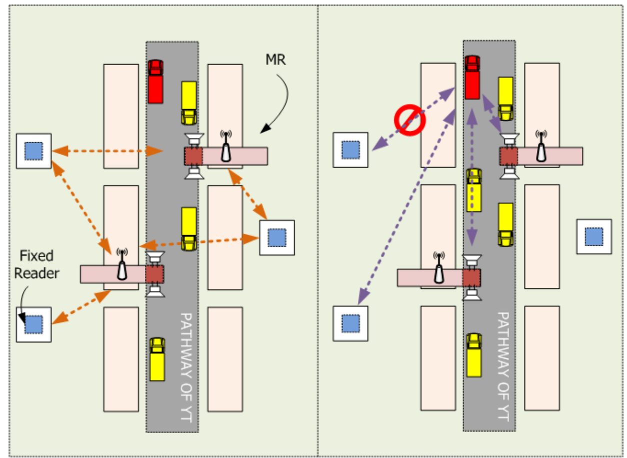

Fig. 7. Two-step communication using mobile readers: mobile readers easily find their location with fixed readers because there's no obstacle between them. Tags communicate with both fixed and mobile readers.

C. Protocols

Now, we explain our protocols for the efficient operation of the locating system in port environments. Fig. 7 shows basic concept of the protocol and Fig. 8 shows the operation diagram. First, each mobile reader attempts to find its own location. The localization of mobile reader is similar to that of the existing system as mentioned previously in section 3-A. Mobile readers attempt to measure their distances from fixed readers and forward this information to the location engine. Tags operate in a manner similar to that of the mobile reader for estimation. Tags attempt to measure the distances with both mobile readers and fixed readers and forward them. However, this operation must be carried out after the estimation of mobile reader. This is because both the locations of mobile readers and the ranging information are required for the estimation phase of the tag. Further, it is possible that a tag communicates with less than three readers; in this circumstance, new location estimation is needed.

D. Design of a location engine

As the location estimation of the tags is always carried out before that of mobile reader, we call this a two-step locating system. The block diagram of a location engine is shown in Fig. 9. Basically, users input some information to the engine, such as the two-dimensional coordinates of the light towers and the pathway of YTs and TCs. The engine includes a logger, a simulator module for system management and efficient processing. Further, a reader manager module controls the readers and communicates with the upper-layer applications or middleware. This module periodically inspects the status of readers, network overheads, and unpredictable events. A result for the calculated location is converted into a message in the packet organizer module and sent to other components such as middleware, logger, or displayer.

The estimation process is composed of a pre-filter, estimator, and a post-filter module. The location engine receives ranging messages, {[tag ID || mobile reader ID], reader ID

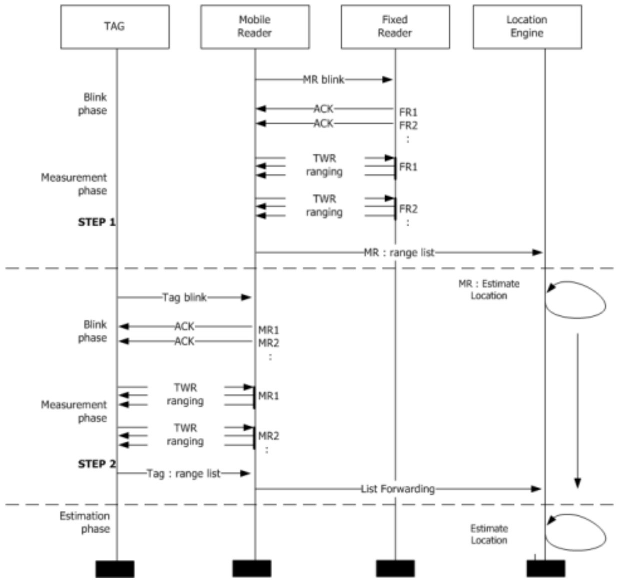

Fig. 8. System protocols

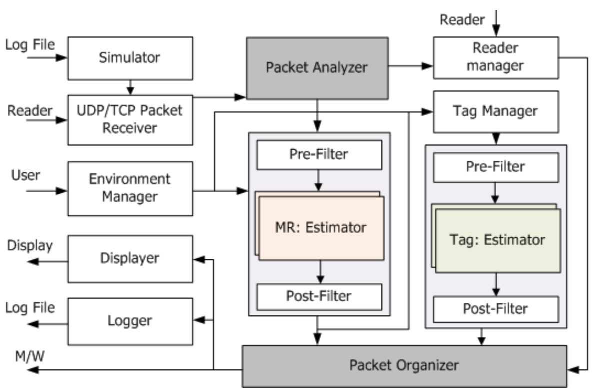

Fig. 9. Block diagram of location engine

list, range list}, depending on a periodic signal from a tag or a mobile reader. The pre-filter module attempts to get rid of any errors included in the raw data of ranging list and compensates ranges from height differences among YT, TC, and light towers.

The estimator module finds the candidate location using the list of calibrated ranging values. In particular, in the installation environment of a port, a tag does not obtain sufficient ranging information. Therefore, it is difficult to calculate the location using tri-lateration or multi-lateration, which uses three or more ranging. Therefore, we suggest different estimation functions according to the amount of ranging information available (LE_1, LE_2, and LE_3); the estimation modules can apply the received packet to each module on a case-by-case basis.

In case of a tag, the estimation module of a tag mainly uses the ranging information of the fixed reader because an error can be included in the location of mobile reader. Further, if a location engine receives three or more ranging, it calls LE_3 and obtains candidate locations, as shown in Fig. 11.

```
GET rangeList from system
CALL preFilter() WITH rangeList RETURNING filteredRangeList
INIT candidateLocs, temp, result, EstimatedTagLoc

IF length of filteredRangeList is over 3 THEN
      GET temp fixed FROM filteredRangeList WITH 3 elements
      CALL LE_3() WITH temp RETURNING candidateLocs

      GET temp fixed FROM filteredRangeList WITH 2 elements
      CALL LE_2() WITH temp RETURNING candidateLocs2
      PUT candidateLoc WITH candidateLocs2

ELSE IF length of filteredRangeList is 2 THEN
      CALL LE_2() WITH filteredRangeList RETURNING candidateLocs

ELSE IF length of filteredRangeList is 1 THEN
      CALL LE_1() WITH filteredRangeList RETURNING candidateLocs

CALL PostFilter() with candidateLocs RETURNING EstimatedTagLoc
```

Fig. 10. Pseudo-code of Estimator(1)

For minimizing an error in the process, it also calls the LE_2 function.

The LE_3 function can be called when the number of ranging is three or more. This function uses multi-lateration as mentioned above and is, in general, mainly called in the phase of the TC estimation.

If the number of ranging information is just one or two, the engine cannot apply any multi-lateration algorithms. The LE_2 function uses previous known location and pathway information. First, it draws two circles using ranging values and calculates the intersection of these circles. The candidate points can be the nearest points of the intersection points on the pathway, as shown in Fig. 12. In the case of LE_1, shown in Fig. 13, the engine draws a circle and finds candidate points using the intersection points with the pathway and the previous known location. In a Fig. 11, 12 and 13, one dot which is on the cross line is calculated location, dots on ways are post-filtered location and others are location from GPS or previous location of the tag.

The post-filter module attempts to choose the best possible point among candidate points from the estimation module. The module prioritizes candidate points by considering the pathway of pre-location and distance from the pre-location and chooses one candidate point as an estimated point with the highest priority.

IV. Evaluation

For the evaluation, we implemented and installed the system components at a part of Hutchison Korea Terminals in Busan, Korea. [12]

A tag includes energy-efficient processor and has smart-reset circuit to guarantee the stability of external interference. And also has 2.4GHz RF module which can ranges with other modules based on CSS-TWR. For evaluation, this device is equipped with a GPS module. The tag installed at a drivers seat, and a dipole antenna is attached on the ceiling of YT.

A Reader has PXA255 processor with SRAM and FLASH modules. This component operates in an embedded Linux OS

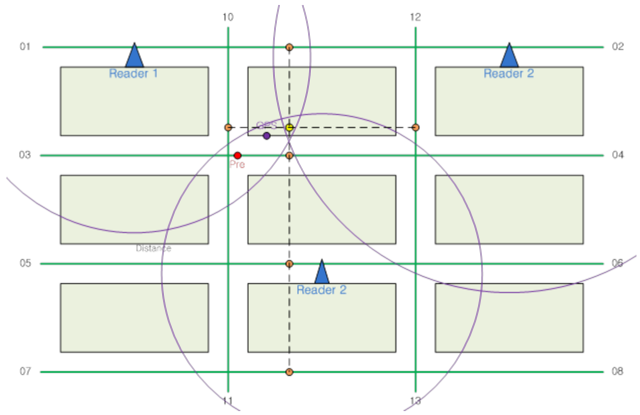

Fig. 11. Operation of function LE_3

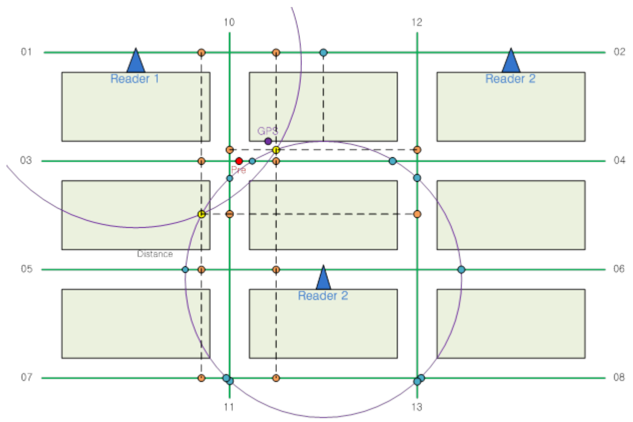

Fig. 12. Operation of function LE_2

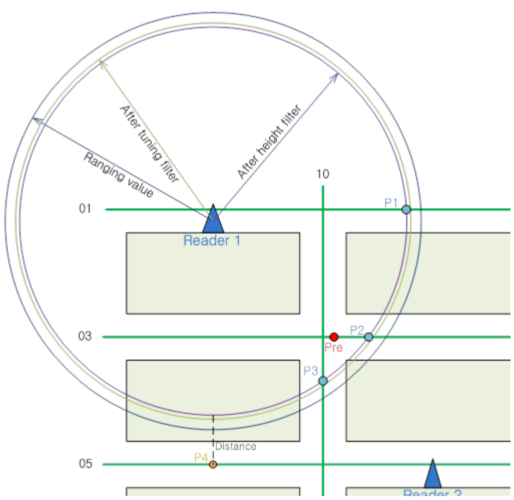

Fig. 13. Operation of function LE_1

```
define function LE_3(rangeList)
    tries to find estimatePoint with rangeList using multilateration method
    CALL findCandidatePoints() WITH estimatePoint RETURNING candidatePoints
    RETURN candidatePoints

define function LE_2(rangeList)
    draws circles with each reader and range
    finds estimatePoints which are intersected from two circles
    CALL findCandidatePoints() WITH estimatePoints RETURNING candidatePoints
    RETURN candidatePoints

define function LE_1(rangeList)
    draw circles with range and location of a reader
    finds pathwayList which are intersected with the circle
    calculates closestPoints from estimatePoints to each pathway from pathwayList
    RETURN closestPoints

define function findCandidateLoc(estimatePoints)
    draws circles with each reader and range
    finds pathwayList which are intersected with circles
    calculates closestPoints from estimatePoints to each pathway from pathwayList
    RETURN closestPoints
```

Fig. 14. Operation of function LE_1

(a) reader platform

(b) tag platform

Fig. 15. Implemented reader and tag

environment and includes LED display and serial interface for debugging or maintenance. For communicating with other application, this device is equipped with an Ethernet interface. There are four RF modules with directional antenna for covering a wide communication area [3][7][9]. Fixed readers are installed at the same height as the mobile readers; mobile readers are installed at the top of the TC. One antenna of a mobile reader is omnidirectional for direct communication with fixed reader, and the others are directional for direct communication with YTs at the pathway.

Hutchison Korea Terminal has 32 TCs, 73 YTs, and 23 light towers in the terminal. The blink interval of mobile reader is 2 seconds, and a tag radiates a blink message every second. If all tags and mobile readers attempt to measure and forward information to a location engine, the engine needs to be able to calculate 89 locations per second. Therefore, we used high-performance hardware and divided processes into I/O, mobile reader, and tag manager processes, for efficient operation.

We evaluated two TCs, two YTs, and all light towers around the TCs and YTs. We measured each location of TC with GPS modules for the reference location. Further, we installed GPS modules with tags for the evaluation. Our

Fig. 16. Installation of system components

TABLE I
NUMBER OF READERS THAT SUCCEED IN MEASURING DISTANCES WITH TCS AND YTS

# of readers	# of communications			
	TC #1	TC #2	YT #1	YT #2
0	69	115	137	131
1	451	55	22	538
2	510	252	494	546
3	63	331	749	444
4	0	170	462	260
5	0	37	127	78
6	0	3	9	3

TABLE II
SUCCESS RATE OF LOCALIZATION

		TC #1	TC #2	YT #1	YT #2
Proposed method	Attempt	1093	963	2000	1500
	Success	1024	851	1863	1461
	Rate	93.69%	88.37%	93.15%	97.40%
ML	Attempt	1093	963	2000	1500
	Success	63	67	654	816
	Rate	5.76%	6.96%	32.70%	54.40%

experiments were conducted more than 1000 times for TC and 2000 times for YT. Table 1 shows the number of readers that succeed in measuring distances with TCs and YTs. A TC could communicate with fixed readers, and an YT could communicate with both fixed readers and mobile readers.

The conventional approach which needs more than three ranges can estimate less than 55 percent of the entire cases. But the new approach of this paper which uses fewer ranges

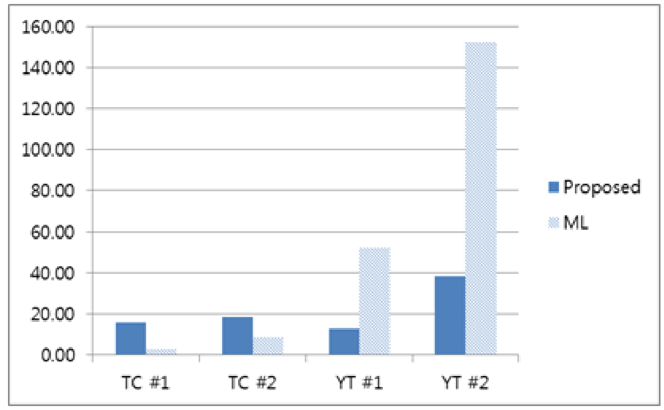

Fig. 17. Comparison of average errors (m)

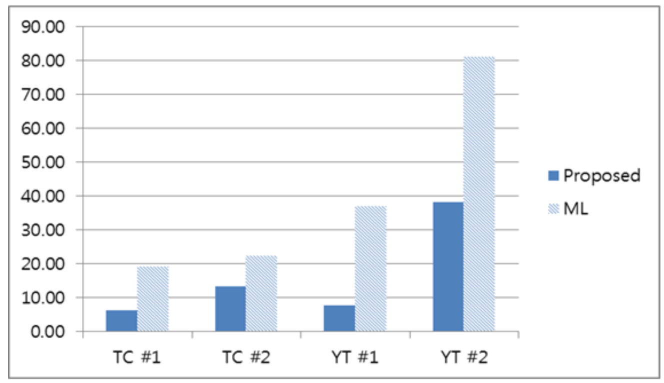

Fig. 18. Comparison of standard deviation (m)

and pathway information can estimate over 85 percent of the entire case. Table 2 shows the success rate of localization. Conventional approach, ML refers to multi-lateration, requires three or more readers. Therefore, the rate of ML is definitely lower than that of the proposed method.

Fig. 17 and 18 show the average error and the standard deviation between the proposed method and the multilateration. We can see that YT #2 has a considerable number of errors that have relatively more ranging information. This shows that YT collects many ranging values from both mobile readers and fixed readers, but some part of these values has error factors due to NLOS communication, such as multipath fading or reflection. Further, the proposed method can calculate the location from a relatively less number of ranging values with a high success rate although the values have error factors. Further, the reference locations of YTs are not quite correct because the estimation of GPS has some delays and the results are not always correct if they are under the overpass or go through a narrow pathway in the experiment.

In case of TC #1 and TC #2, the precision of proposed system is less than previous system. When the number of readers is lower, the precision can be lower. Because the previous system calculates its location only when the number of readers is more than three, the system looks accurate. But as we can see in Table II, the location success rate is much

less than the proposed system, the system performance can be terrible.

V. Conclusion and Future Works

In this paper, we proposed a new locating system for a real port environment. For efficient communication, the readers are classified into fixed readers and mobile readers. Therefore, the localization can be divided into two steps for avoiding NLOS communication. We implemented and installed each component of the system at the real port. In the evaluation, we could see that the proposed system exhibited superior performance to that of the existing system, and we found that the proposed system can be applied to a real port.

However, for evaluation, it is hard to find the actual location for comparing with estimated location from the system at a specific time. The output of a GPS module which is a reference point in our evaluation can include inaccurate values or update delay when therere lots of steel objects and narrow paths in a port environment. So the result of evaluation cannot be much accurate in this paper. Therefore we try to research more accurate evaluation of our suggested method. And also the research for filtering NLOS-conditioned range information can be included for future works.

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